Chapter

UHF RFID in a Metallic Harsh Environment

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Abstract

The use of the UHF RFID system in a warehouse that contains steel coils is a challenge for the technology itself since there are countless reflections of the radio frequency waves in the environment causing the multipath effect, which represents one of the most complex problems for wireless communication. Thus, this effect must be managed with the hardware, such as the antenna radiation diagram, and with the software, in the middleware, the software developed for the application. In this chapter, an application of RFID in metallic items will be discussed, tracking them since the product's hot rolling, controlling the receiving process, shipping, and inventory, working together with equipment such as overhead crane.

Keywords: RFID, UHF RFID system, logistic, harsh environment, RFID in metallic

1. Introduction

RFID (Radio Frequency Identification) is an identification technology that uses a magnetic field or electromagnetic waves to access data stored in a microchip that is connected to a small antenna attached to an object.

The RFID system uses the magnetic field at LF (125 kHz) or HF (13.56 MHz) frequencies for communication between the transmitter and receiver. This communication typically has a maximum range of 20 cm, named NFC (Near Field Communication), that is, it is a short-range wireless connectivity technology, which transfers energy to the tag through inductive coupling.

However, for the frequencies used in the RFID system in the UHF band (860 MHz - 960 MHz) there is also a magnetic field constituted near the transmission antenna (near field), which is well defined at this distance. As the magnetic field spreads, an electric field develops. These fields, magnetic (near field) and electric (developed), add up orthogonally and the result is an electromagnetic field. This electromagnetic field has the property of propagation and propagates in the form of an electromagnetic wave, moving away from the transmitting antenna. In this way, when a UHF RFID tag is hit by this electromagnetic wave, coupling occurs. In other words, the energy of the electromagnetic wave captured by the RFID tag antenna energizes the microchip (IC - Integrated Circuit). With this, the IC internally performs its functions and returns its data, object identification and other information that are stored in its memory, to the RFID UHF reader through another electromagnetic wave created by the IC. This description refers to a backscatter coupling.

Typically, due to physical properties, the RFID system at LF and HF frequencies have an easier time reading their tags when they are on objects containing metal, liquids, wood and due to their type of coupling (inductive coupling), which does

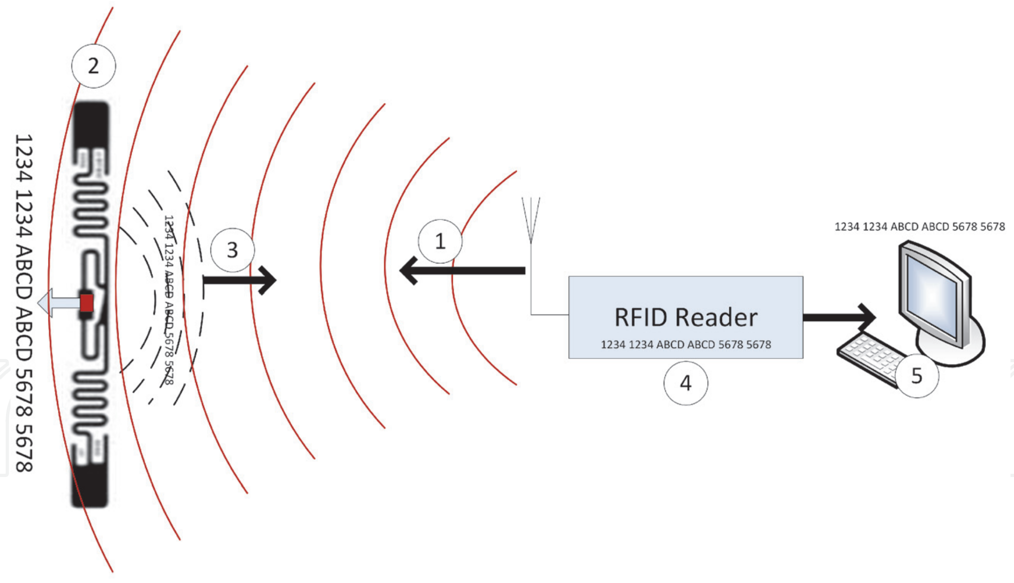

Figure 1.
Overview of an RFID system with backscatter coupling.

not occur with the UHF RFID system. The electromagnetic wave that propagates is strongly influenced by the environment in which the RFID system is implemented and is dominated by the same phenomena that characterize any radio signal, that is, reflection, diffraction, and refraction. These phenomena can alter the amplitude, phase or frequency characteristics of the electromagnetic wave and cause signals of multiple paths, making it difficult to implement the UHF RFID system.

The great challenge of implementing a UHF RFID system in a metallic environment is to control these multipath signals, in which the variables in the environment are numerous and which cause a very unstable signal level, both from the reader to the tag and from the tag to the reader.

1.1 Overview of a UHF RFID system

The overview of an RFID system with backscatter coupling is shown in **Figure 1** [1]. In this figure, at the beginning of the process (1), the RFID reader creates an electromagnetic wave and transmits it.

When the electromagnetic wave meets an RFID tag, the backscatter coupling occurs (2). With the energy resulting from the coupling, the microchip (IC) performs its functions and sends the contents of its memory to the reader through another wave created by it (3).

Upon receiving the wave with the IC memory, the reader demodulates the signal and obtains the data and amplifies them to send to the computer (4).

With this data, the computer performs its functions, such as grouping, filtering and, in this way, prepares them for the application (5).

2. UHF RFID system in a metallic environment

A typical RFID system is divided into two layers: physical and software.

In the physical layer, there are readers, also called interrogators, which functions are: to generate radio frequency energy and query signals and send them through one or more antennas; receiving replies to the queries from RFID tags, amplifying and demodulating these signals; organizing the data received from the RFID tags and, finally, sending them to a computer or a network.

In this way, a reader must have at least one antenna, which is the communication interface with an RFID tag, and an interface for communication with the computer, which can be a serial or USB output, an Ethernet output, Wi-Fi, Bluetooth, 3G.

RFID tags also belong to the physical layer and consist of an inlay, which, in turn, consists of: a microchip or integrated circuit (IC). The data, the unique identification of the object and other information, are stored in the memory of this IC, which is also responsible for several essential processes for communication with the reader to occur; antenna: responsible for receiving and sending radio frequency waves. The shape of the antenna depends on the frequency of operation of the system; connectors: connect the IC to the antenna; substrate: the support base of the antenna, the IC and the connectors. It contains electrical characteristics that are considered in the design of the antenna.

The inlay can be encapsulated or not. Both the material to be used for the encapsulation and its format will be defined according to the characteristics of the application. Thus, an RFID tag can be provided in many shapes, types and sizes.

Still belonging to the physical layer it is the interrogation zone. The interrogation zone represents the area in which the RFID reader is able to activate and obtain an answer from an RFID tag, one of the crucial points for any implantation.

The RFID software layer, named middleware, goes beyond simply connecting devices. It allows all necessary applications for the RFID system, as filttering, giving hability to manage data and other applications for the user.

3. Attributes for the implementation of the RFID system

The key attributes for implementing the RFID system in a metallic environment and achieving success with the system are: process vision; requirements for implementing the RFID system within the existing process; the necessary resources for the implementation of the RFID system and; finally, the implementation action plan.

3.1 Process view

The entirely process understanding and knowledge of its features in which the RFID system will be implemented is as important as the RFID technology itself. Understanding the challenges of the process and, consequently, make them suitable for the specific application and determine the best RFID system for this process is crucial. Without this essential view of the process, a mistake in the results of the implementation of the RFID system could occur and, consequently, wrong deliveries to the customer.

For example, the RFID system will be used to identify steel coils (steel wire rod), **Figure 2**.

The steel coils are produced in the rolling mill, where they receive a label for their identification of batch and type of material. The identification tag is attached to the coil manually. After weighing and printing the label with the identification, an operator fixes it to the coil by means of a clamp on one of the coil's ties.

Inside the laminator, the rollers are transported by a type C hook until unloading to the transfer carriage. After labeling, the rollers continue, taken by the hook, towards the transfer cart and finally deposited on the bed. The bed is the delivery point of the rolls for logistics. When the rollers are in bed, it is already the responsibility of the logistics department.

Figure 2.
Steel wire rod.

The coils, under the responsibility of logistics, are stored internally in a warehouse and transported through an overhead crane, as outlined in **Figure 3**.

The destination of the stored coils is for sale to the foreign market, so their transportation is done by trucks or train cars.

In short, the RFID system will be used for storage management. The storage management comprises the flow of the coils, their movement, storage, until the order is picking and shipment [2]. However, with the RFID system, picking is a step that will be eliminated, as the system allows the coils to be removed from the storage position and to be directly shipped for transportation, as shown in the flow in **Figure 4**.

3.2 RFID system implementation requirements

After analyzing the process in depth, a thorough approach to analyze the specific need to use the RFID system and is necessary. After this step, design the system architecture solution with the best cost–benefit ratio. Without these basic requirements there may be an unrealistic expectation in the delivery of the RFID project.

Below are some important aspects of the application:

- The RFID system will be implemented to facilitate the logistics processes of receiving, shipping and inventory.
- The RFID system data must be integrated with the logistics management system.
- Logistic processes require the correct storage position within the warehouse.

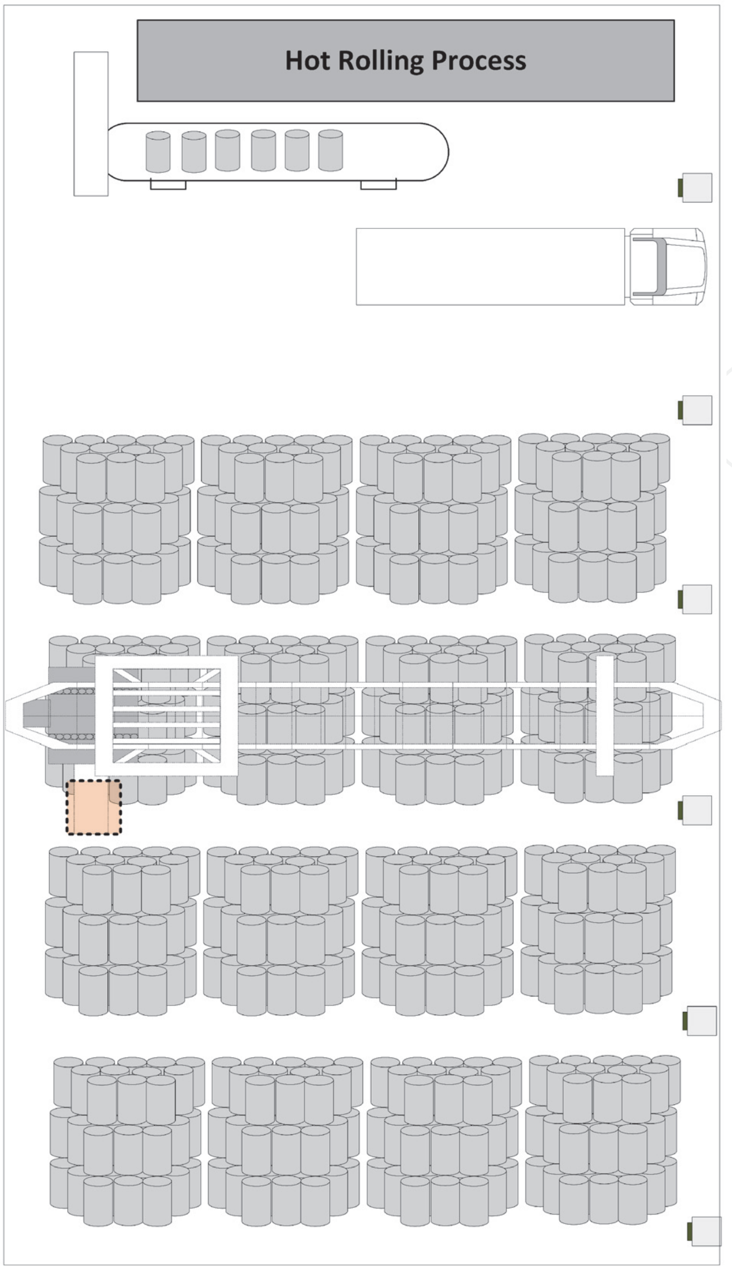

Figure 3.
Storage of steel wire rods.

- The object to be identified: steel coil.
- Steel coils are transported via an electromagnet overhead crane. An operator should never be under a suspended load.
- Steel coils leave the rolling process at high temperatures. The temperature depends on the gauge of the steel. However, coil cooling decreases very fast. **Figure 5** shows the exit temperature of the laminator of a steel coil with $113.5^{o}C$.

3.3 Resources for implementing the RFID system

The resources for the implementation must be mapped so that there is no frustration with the RFID system. The resources are divided into financial and human resources.

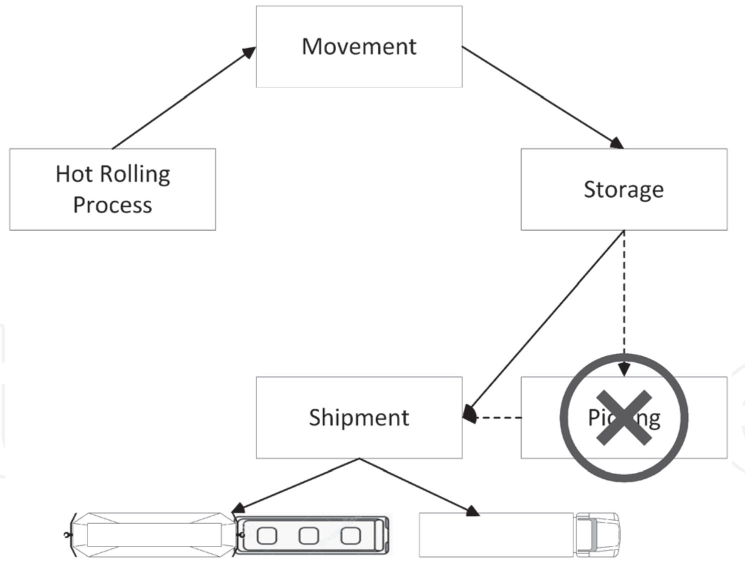

Figure 4.
Storage management flows - with RFID, the picking step is eliminated.

Figure 5.
Coil temperature at the hot rolling process outlet at 113.5°C.

3.3.1 Financial resources

The financial resource is an estimate of the necessary amount of financial resources for the project. The estimated budget is obtained through a business plan based on the architecture of the solution and aligned with the objectives that justify the implementation of the RFID system attending the expected project goals.

The business plan helps to obtain the correct investment decisions and must be focused on defining the problem that the RFID system will solve, considering the objectives and risks that the organization will face when implementing this technology. The definition of objectives at the beginning of the process will ensure that the design of the solution is monitored both during implementation and at the conclusion of the steps and their deliveries; consequently, it will bring subsidies to monitor the evolution of the implementation of the RFID system.

For a steel industry, improving the working conditions and protecting healthcare of their operators are the main objectives for the implementation of the RFID system in coil storage, i.e. the focus is on work safety of their employees. The automatic collection of the coil identification removes the operator from the storage area and considerably reduces the risk of accidents with the coil falling during its transport on the overhead crane.

Business performance can also be scored and should consider: the efficiency of steel coil circulation, inventory management, more effective inventory control, improving operational productivity by reducing management costs, reducing lead times coil loading for road or rail transport.

3.3.2 Human resource

The human resource is the project team needed for the implementation. The RFID system is a complex system and involves hardware and software, so the team must consist of at least:

- 01 radio frequency specialist;
- 01 overhead crane maintenance technician;
- 01 software developer for the development of the RFID Middleware; and,
- 01 project manager

3.4 Action plan for the RFID implementation

An inadequate action plan leads to a false start in the implementation, and as a result, mismatched and uncertain delivery dates. For this reason the action plan must be carefully elaborated and must provide details of all activities involved as who will be in charge and how the piece of necessary information is going to be provided.

The action plan can be divided into four stages: conceptual phase, which describes the initial vision and the basic objectives of the project and the business plan itself; planning phase, which consists of an analytical structure of projects carried out by the project manager, involving responsibility for the work and interrelated tasks; installation phase, which is the stage in which it is possible to identify and purchase all the equipment and software that will be part of the solution. The installation phase will remain until all software and hardware installations in the approval environment are completed, for testing and validation, and later, the turn to the production environment. In this phase, the project manager transfers the project to the operating personnel along with all project documentation, including the service and governance plan.

4. Solution design

In order to analyze the feasibility of implementing the RFID system for identification in steel coils, a proof of concept is required. Proof of concept (POC) is an activity that demonstrates, in the installation environment itself, electromagnetic interference in real conditions and the most appropriate RFID tag for the operation, consequently, the POC identifies the challenges that the implementation of the RFID system will face in this hostile environment for radio frequency.

4.1 The physical layer

4.1.1 RFID tag

The temperature in the steel coils is a variable analyzed in the proof of concept, as it will determine the type of RFID tag for the system.

A coil has three sectors divided into head, middle and tail. The RFID tag must be placed on its tail and on the inside part, named as the cold zone. For this reason, the temperature measurement in the POC must be performed on the steel coil on its tail and inside it at the time of the hot rolling process exit after cooling, according to the points indicated in **Figure 6**, using a FLUKE thermometer.

Table 1 shows the temperatures measured at the exit of the laminator at measuring points 1, 2, 3 and 4, as shown in **Figure 6**, performed at an ambient temperature of $23^o C$.

In addition to the measurement shown in **Table 1**, the coil temperatures must be recorded during the storage process, that is, on the scale, in the storage place after transportation with the overhead crane and after 40 minutes of storage. As an example, the following coil gauges were chosen for measurement: 31.75 mm and 7 mm, as the gauge directly influences the temperature, as well as the chemical

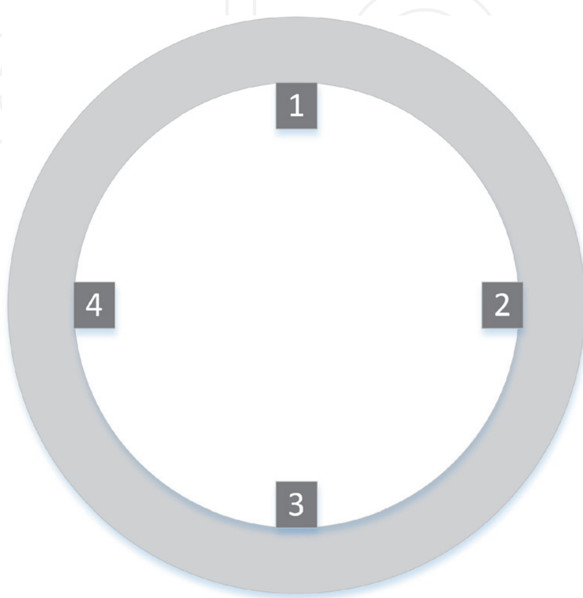

Figure 6.
Temperature measurement points on the steel coil tail after rolling.

Point 1	Point 2	Point 3	Point 4
60.7^oC	47^oC	36^oC	55^oC
68^oC	44^oC	39^oC	52.1^oC
55^oC	41^oC	35.8^oC	52.5^oC
61.7^oC	50.7^oC	38.8^oC	41.3^oC
60.9^oC	52.9^oC	42.5^oC	50.3^oC
74.8^oC	60^oC	47.3^oC	58.1^oC
182.1^oC	118.8^oC	117.1^oC	124.1^oC
115^oC	73.2^oC	97.9^oC	113.5^oC
135^oC	98^oC	107.6^oC	119^oC
158^oC	102^oC	108^oC	98^oC

Table 1.
Temperature in the coils at the measuring points at the power plant exit.

composition of the steel, among other factors, however, these characteristics were not considered in this work.

After the first 20 laminated pieces, it is suggested to start measuring the temperature of the 04 posterior coils, named X1, X2, X3 and X4, in point 1, to check if there will be a higher temperature in relation to the other measured points, which could occur. **Table 2** shows the coil temperatures of 31.75 mm during the storage process of 04 (four) coils, referring to the location where the coil was during the measurement, the coil and the respective temperature ^oC. **Table 3** shows the coil temperatures of 7.0 mm.

Looking at **Table 2** and **Table 3**, it can be seen that 100% of the 31,75 mm and 7 mm gauge coils are above the maximum operating temperature desired for the RFID system in all storage locations, as can be seen in the graph of **Figure 7** and this is a challenge for the implementation of the RFID system, as these conditions can affect the reading distance and the reading rates.

The functional and performance requirements of an RFID tag are influenced by the temperature at which it is submitted. An example can be seen in **Table 4** presented in the technical specifications of the Impinj Monza 4 RFID Tag IC [3].

Place	X1	X2	X3	X4
Weight Balance	180^oC	140^oC	140^oC	125^oC
Overhead crane	136^oC	118^oC	116^oC	106^oC
min after storage	120^oC	90^oC	90^oC	90^oC

Table 2.
Coil temperatures of 31.75 mm during storage process.

Place	X5	X6	X7	X8
Weight Balance	199^oC	202^oC	220^oC	238^oC
Overhead crane	176^oC	182^oC	192^oC	217^oC
min after storage	100^oC	140^oC	123^oC	134^oC

Table 3.
Coil temperatures of 7.0 mm during storage process.

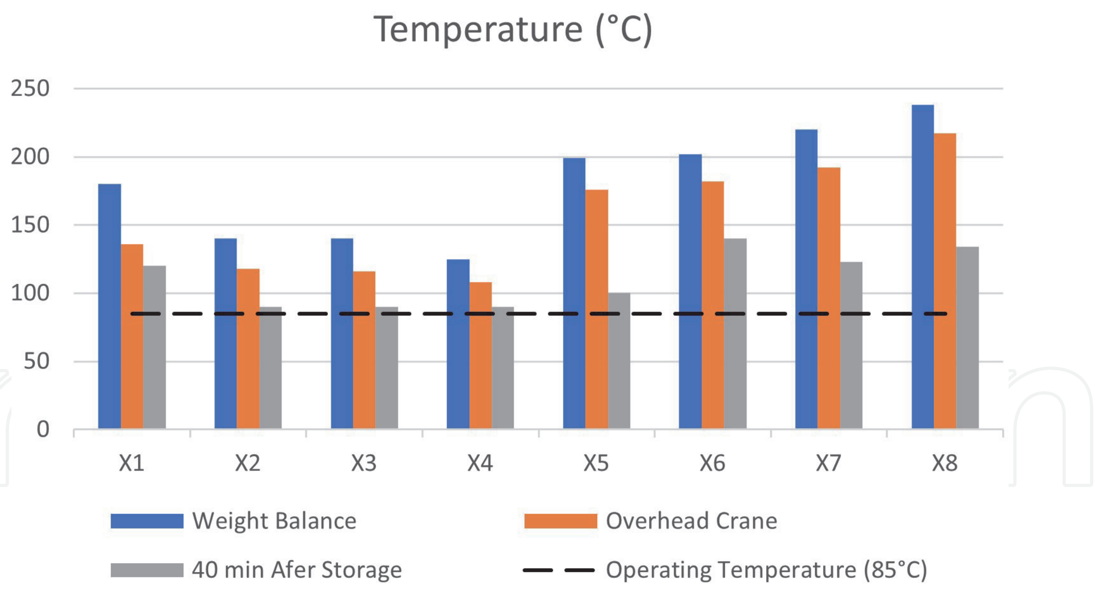

Figure 7.
Temperature of coils X1, X2, X3 and X4 (31.7 mm) and X5, X6, X7 and X8 (7 mm) in the different storage locations and the operating temperature of the RFID system.

Parameter	Minimum	Maximum	Units	Comments
Extended	−40	+85	^oC	Default range for all requirements
Operating				functional and performance
Temperature				requirements
Storage	−40	+85/+125	^oC	At 125^oC
Temperature				data retention is 1 year
Assembly		+150	^oC	Applied for one minute
Survival				for one minute
Temperature				

Table 4.
Temperature parameters – Impinj Monza 4 tag Chip.

A solution to the high temperatures of the product is to use RFID tags developed by several suppliers of special tags. **Table 5** presents the specification of some High Temperature UHF RFID Tags developed by some worldwide recognized manufacturers that would the possible to be used in the mentioned RFID application.

However this solution makes the project unfeasible due to the price of these tags, due to the current Brazilian market complex tax system as import duties, taxes, shipping fees, and a few other costs applied when importing goods to Brazil.

Another solution for high temperature is to encapsulate the tag to protect it and prevent damage to the IC or to the connector that connects the antenna to the IC. This solution was designed specifically for the characteristics of the project and developed in the country itself, with no import cost. This was the recommended solution as it enabled the project in the RFID tag requisite.

4.1.2 RFID reader

The RFID reader is a device that reads, writes and processes the data on the tags and sends them to an application. Finally, it is responsible for remotely energizing

Specifications	HID [4]	Omni-ID [5]	Confidex [6]
	High Temperature Label	IQ 800P HT	Heatwave Flag
Operating Frequency (MHz)	865 to 956	860 to 960	865 to 928
Read Range	Up to 8 m	Up to 8 m	Up to 10 m
Application Temperature	+230^oC	+230^oC	+230^oC
Dimensions (mm)	80 × 50 × 0.5	85 × 55 × 0.49	76 × 55 × 0.37
IC type	Monza 4QT	Alien Higgs-3	Alien Higgs-9
Housing Material	Aramid polymer	High temperature synthetic label	Special polymer designed for high temperatures

Table 5.
Physical specifications - UHF RFID tag - High Temperature.

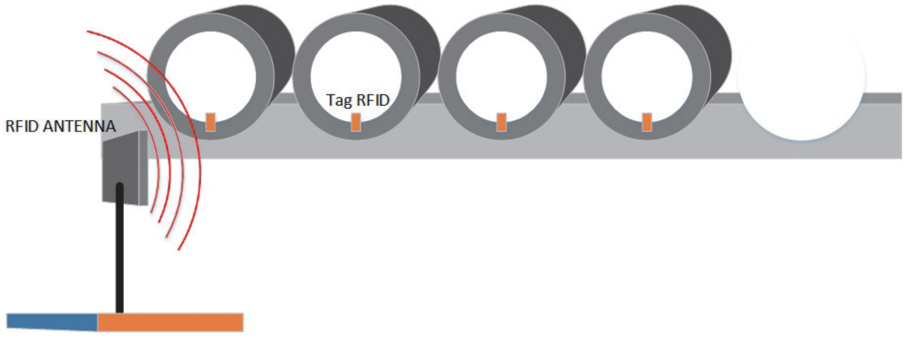

Figure 8.
RFID reader at the output of the laminator.

RFID tags and obtaining the data contained in them. The reader can also perform filtering and data collection functions, and manage equipment input and output.

The reading of the RFID tags on the bed is performed by a fixed reader with an antenna, as shown in **Figure 8**.

The reader must be installed in a metallic distribution board of overlapping NEMA Norm category 4 with ventilation. This protection will prevent the conditions of the environment, high temperatures coming from the laminator, and dust, do not cause the interruption of its operation due to the temperature control. Reinforcing that the RFID reader is an electronic equipment and requires operating temperatures between -20^oC to $+50^oC$ [7].

The automatic receipt of the identification of the coils through the RFID system allows the status of the entry in the logistics sector to be more assertive, with verification of the material of the coil with which it was requested for hot rolling process, in addition to the analysis of the return of non-compliant materials, together with the integration of the WMS system (Warehouse Management System), increasing the quality and speed of the information in order to rationalize and optimize the storage logistics and the management of coil stocks.

Leaving the hot rolling process, in the movement stage, the identification of the coils by the RFID system must be performed by a reader installed on the electromagnet overhead crane itself.

4.2 Environment

4.2.1 Electromagnet overhead crane

A feasibility test of the RFID system must be carried out on the electromagnet overhead crane for the movement of steel coils in the storage area. For this, an RFID antenna must be attached to the overhead crane connected to a fixed RFID reader, in order to the performance tests of reading the RFID tags attached to the steel coil. The number of coils for the test must be according to the number of coils that the bridge's electromagnet car supports. For two coils, the RFID tag reading must be analyzed for these two coils, for four coils, the reading must be analyzed for four coils, and so on. Assuming the reading for two coils, the tests are carried out on two steel coils moved simultaneously with activation of the electromagnet. In this way, the RFID tags of the two coils are read with the system in a static way and with the system in motion.

In order to simulate a real situation, RFID tags must be fixed by the operator himself and in accordance to the process already used for this purpose. Thus, the RFID tags are inside the wire rod as shown in **Figure 9**.

With the system activated, consequently, the electromagnet turned on, **Figure 10**, the analysis of the frequency behavior through a spectrum analyzer occurs, **Figure 11**. Simultaneously, the reading of the RFID tags is obtained. The RFID tag must be read with both in the static and in motion systems.

It is verified in the spectrum analyzer that the magnetic field emitted by the electromagnet of the overhead crane is superimposed on the electromagnetic field of the RFID system. The magnetic field does not interfere with the electromagnetic field of the RFID system.

In **Figure 11** it is also possible to see the hopping channels of the Frequency Hopping Spread-Spectrum (FHSS) technology used in the RFID system according to the rules of the Brazilian regulation established by ANATEL (National Telecommunications Agency). It is important to note that the technology Frequency Hopping (FH) operates with a number of fixed channels stipulated by the country's regulatory agency. In the case of Brazil, 35 hop channels for the RFID system are used in the frequency range of 902 to 907.5 MHz and 915 to 928 MHz.

The FH technology uses these channels to send and receive the signals from the RFID system during a time interval established by the standard and in a sequence of use of each pseudo-random channel, thus reducing the probability of interference from other systems that use the same band of frequency.

Results: there is no interference of the magnetic field in the electromagnetic signal of the RFID system and the reading of the RFID tag is performed successfully, as shown in **Figure 11**. Therefore, the test results are positive in this scenario and the movement of the coils can be carried out by the overhead crane in the inner courtyard. Thus, it completes the storage management cycle by supporting the storage and shipping steps with the RFID system by sending the coil identifications to the logistics management system that the organization uses.

4.3 Software layer

The software layer consists of the RFID Middleware. It is a set of software components that act as a bridge between the components of the RFID system (in

Figure 9.
RFID antenna installed on the overhead crane for the RFID tag reading tests.

this case, RFID readers) and the application (logistics management system) of the organization that will receive the events generated by the RFID system. It needs to provide two main functions: monitoring the health and status of RFID devices, readers and reader antennas; and, manage the infrastructure and data flow specific to the RFID system.

For the system proposed in this chapter, the development of the RFID middleware considers: centralization of the reception of events generated by RFID readers in each equipment in which the RFID system will be installed, overhead crane and laminator bed; filtering and processing messages; interpretation of the message sequence according to the needs of the storage management system; forwarding messages to the storage management system. In addition, a system for monitoring the entire RFID system, including the monitoring of readers and their respective antennas, should also be considered.

The big challenge is to mitigate interference. The interference in the proposed system is considered when there is a reading of the identification of the steel coils that are not the desired ones, called unwanted coils. The interference occurs when there is reflection of the radiofrequency wave signal in the coils stored in the storage area and, consequently, the identification of unwanted coils is read by the RFID system installed on the bridge. This phenomenon is more evident when the overhead crane moves over the high stock, that is, many coils stored with stacking them in several overlapping layers.

Figure 10.
Steel coils with RFID tags lifted by the overhead crane, magnetic field emission in the environment.

Figure 11.
Spectrum analyzer measuring the frequencies radiated in the environment during the RFID reading tests with the electromagnetic overhead crane connected.

4.3.1 Mitigation of interference

The mitigation of interference must be performed at the hardware layer and at the software layer.

In the hardware layer, the interference is mitigated by adjusting the minimum power required to read the identification of the desired steel coils. This is done by adjusting the reader power of each RFID antenna with the static system, overhead crane stopped, loading the coils and positioned on top of the stock.

The software layer, on the other hand, must be responsible to solve the interference that still resulted with the power adjustments. For this, the development of the middleware must contain an established result interpretation logic that eliminates the reading of unwanted coils during the movement of the overhead crane.

The readings that occur in the movement of the overhead crane over the high stock, with the desired coils hoisted by the electromagnet. These readings always contain the identification of the desired coils. However, the reading of the identification of unwanted coils is shown punctually during movement, being eliminated during the journey. The problem is when the route is not long enough for these readings to disappear and not be sent to the management system improperly, and thus, the need for the logic of interpretation of the results. The problem occurs when the path is not long enough for these readings disappear and not be sent to the management system improperly, and thus, there is a need for the logic of interpretation of the results.

The logic of interpretation of the results must be analyzed for each situation of the RFID system, that is, not only when it comes to the RFID solution in overhead crane, but also a logic for each RFID system installed in environments such as the one mentioned in this chapter, a logic for the receiving RFID system, reader installed in the laminator bed and a totally different logic for the RFID system on the overhead crane, which will be true when the system is installed on forklifts, for example.

Therefore, the logic of interpretation of the results must be analyzed case by case when implementing the RFID system in metallic environments and this logic will be responsible for the quality of the delivery of events that are generated by the RFID system and delivered to the storage management system.

5. Conclusions

The implementation of the RFID system is possible in a warehouse that contains steel coils, since the necessary attributes for the successful use of this technology are observed. The attributes are divided into four stages: view of the process; requirements for implementation; the necessary resources; and the mapping of the action plan.

The vision of the process is the first step, and it must occur even before the implementation. It represents one of the most important factors in the whole process, as it presents all the challenges that the RFID system will face and serves as a foundation for the other steps. After analyzing the process, the requirements must be very well mapped for a successful implementation. They must contain the most important aspects for the application of the RFID system, such as: the logistical processes that the RFID system will support; the intrinsic variables of the process, item temperature, storage conditions, for example; type of transport that the item will use; safety conditions for the employees; etc.

Resources are divided into two sectors: financial and human. Without the necessary resources for the implementation of the RFID system, especially in a harsh environment, such as the storage of steel coils, the RFID system, during its implementation, can bring some frustration in the deliveries since there will not be trained people available nor financial support for the project on how to proceed correctly. The last step of the attributes is the action plan. The action plan includes the design of the project, the approvals, both of software and hardware in a test environment and, finally, the delivery of the solution in a production environment.

In case there is high temperature in the item that will use the RFID system, the RFID tag must be carefully studied. There are many market solutions for tags for these items, however, the cost can turn the RFID implementation unfeasible and another effective solution should be studied so that the RFID tag is able to support the variables that involve this type of application.

The RFID Middleware, i.e., the software that has the native function of collecting, filtering and grouping raw data sent from RFID tags and collected by the RFID readers, will also insert some business rules necessary for the implementation. The Middleware is also in charge of dealing with the interference arising from the environment so that a successful RFID implementation may occur. In short, the RFID Middleware plays an extremely important role in the whole context making possible to get success in the RFID implemented system in such a harsh environment when dealing with a technology that uses radio frequency at the frequency of 900 MHz.

Abbreviations

RFID	radio frequency identification
UHF	ultra high frequency
LF	low frequency
HF	high frequency
NFC	near field communication
IC	integrated circuit
USB	universal serial bus
POC	proof of concept
FHSS	frequency hopping spread-spectrum
ANATEL	National Telecommunications Agency

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